PULVERIZED COAL NO_x CONTROL: RECENT EXPERIENCE WITH AN ADVANCED LOW NO_x BURNER RETROFIT

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In June 1997, a retrofit of an advanced low NO_x burner to a 440 MWG pulverized coal steam generator was undertaken. The goals of this retrofit were to reduce NO_x emissions below 0.45 lb./10^6 Btu under all operating conditions (including 5% over pressure, all mills in service, or any one mill out of service) and to improve reliability by eliminating burner coking during normal operation. All of our goals have been met: NO_x emissions are significantly below the guarantee level with no detrimental effect to boiler operation or efficiency.

This boiler had been equipped with the OEM's 1986 vintage low NO_x burner. Rather than replace the entire burner, ABT supplied an advanced fuel injector and upgrades to the remainder of the burner. The result is effectively a new low NO_x burner that, at a minimum cost, attains 25-35 % lower NO_x than the original equipment. The low NO_x levels being attained are of particular significance since this unit is not equipped with overfire air ports. This experience has direct implications not only for other boilers of this type but also for group II pulverized coal boilers.

INTRODUCTION

A new internally staged fuel injector concept, developed by Advanced Burner Technologies Corp., has been installed on the Bonanza Unit #1 of Deseret Generation & Transmission Coop. Start-up was June 1, 1997. The Opti-Flow™ fuel injector has been developed for use on all types of pulverized coal wall-fired boilers regardless of original burner type. Complete retrofits, including a new dual register design, can be made where necessary. Alternatively, upgrades to existing low NO_x burners or conversion of turbulent high NO_x burners can be made at a minimum cost. Deseret chose the latter option since Bonanza #1 was equipped with the original equipment manufacturer's low NO_x burner.

Bonanza #1, shown in *Figure 1*, is a Foster Wheeler 440 MWG opposed-fired boiler that was originally equipped with Foster Wheeler controlled flow/split-flame low NO_x burners as the only means of NO_x control. The unit is not equipped with overfire air ports. *Figure 2* is an illustration of the original CF/SF low NO_x burner. The twenty burners are fed by five MBF vertical pulverizers.

REASONS FOR THE RETROFIT

Although the boiler and burners generally operated satisfactorily, there were several combustion and reliability issues that needed to be addressed.

- COKING AND BURNER FIRES: The scroll-based fuel injector is subject to coal layout within the scroll and along the anti-roping bars that are circumferentially located around the inside of the fuel injector's outer sleeve. Coal dropout is also common on top of the fuel injector's inner sleeve. With many coals these accumulations do not cause problems. However, some coals will coke and ultimately cause fires within the fuel injector. On Bonanza #1 there were several severe burner fires which caused extensive damage. Consequently, one of Deseret's criteria for a replacement burner was the elimination of coal layout/dropout and the resultant propensity for coking and fires.
- NO_x DURING NORMAL OPERATION: Deseret had opted-in to the EPA NO_x reduction program requiring the unit's NO_x level to be reduced below 0.5 lb/10^6 Btu. However, the OEM burners were not capable of maintaining this level at full load. Therefore, the operators would remove one mill, typically the mill feeding the top front burner deck, from service in order to reduce the NO_x level.
- NO_x AT MAXIMUM LOAD @ 5% OVER PRESSURE: The unit can generate approximately 455 MW at 5% OP with the existing turbine configuration. Under this condition the top front burner deck had to be constantly removed from service in order for the unit to remain in NO_x compliance.

Although removing the top burner deck from service will reduce NO_x as compared to the configuration of all burners in service, this method of operation has several drawbacks:

- Boiler operational flexibility is severely limited.
- In-service mills constantly operate at maximum load, which results in deterioration of fineness. This causes higher unburned carbon and thereby decreases boiler thermal efficiency.
- Mills wear unevenly, with the top mill wearing at the lowest rate. Eventually one of the remaining mills must be removed from service for maintenance. The operators then have the Hobson's choice of either exceeding the NO_x regulation by returning the top mill to service to maintain load or dropping load if the top mill is kept out of service.
- Maximum load cannot be maintained when coal quality deteriorates. If NO_x considerations did not require a specific mill to be out of service, maximum load could be attained whenever needed.

In December 1996, Deseret contracted with ABT to upgrade the OEM-supplied low NO_x burners to the Opti-Flow™ design. Complete material warrantees and performance guarantees for emissions and boiler operation were provided. *Table I* summarizes the guarantees.

Table I

BONANZA #1 GUARANTEES	
Load (% MCR)	100 @ 5%OP
NOX (lb/106 Btu)	<0.45
CO (PPM)	<100
UBC (%)	No Meas. Incr.
BOILER PERFORMANCE	
SH/RH	1005/1005
Eco. Out Gas Temp.	No Incr.
Unit Efficiency (%)	No Decr.
Fuel Injector DP:	Significant Decr.
Coking:	None

The unit also suffered from formation of significant "eyebrows", 3-5 ft long, over each of the burner throats. ABT predicted that the slag accumulation would be significantly reduced or eliminated after the retrofit.

ABT proposed to meet the above guarantees by modifying the existing dual registers and upgrading the original fuel injector to the Opti-Flow™ design while retaining the maximum amount of existing hardware. This method minimizes the costs of both material supply and installation.

THE OPTI-FLOW™ LOW NO_x BURNER

ABT has developed a new low NO_x burner and fuel injector design. The burner concept includes a register design that provides complete control of the secondary air to, and within, each burner. The key component for NO_x control is the Opti-Flow™ fuel injector that can be configured for use with a scroll or elbow type of inlet, as shown in *Figure 3*. Since Bonanza #1 is equipped with a scroll inlet and replacing the scroll with a different inlet would have significantly increased costs without providing additional performance gain, the scroll was retained. The following discussion of the new design is specific to this retrofit, although a similar discussion could be presented for fuel injectors using other types of inlets.

As illustrated in *Figure 3*, the scroll-based Opti-Flow™ fuel injector consists of three components:

- TAPERED TRANSITION SECTION—The new transition section connects to the scroll. Internally, the transition has a proprietary geometry and vane system that simultaneously increases the axial velocity of the primary air/coal mixture above the saltation level and converts the flow from 100% rotational to 100% axial.
- CYLINDRICAL OUTER SLEEVE—The axially directed mixture flows through the outer sleeve prior to entering the nozzle.
- SEGMENTED COAL NOZZLE WITH INTEGRAL STABILIZERS—The nozzle has an open cross-section with no sites for coal adhesion and a smooth, continuously variable surface with minimum stress concentration points. These features assure both freedom from coking and mechanical integrity to maximize lifetime.

Figure 4 is an illustration of the nozzle showing the open nature of the passages and the integral stabilizers for each segment. As secondary air flows over the exterior of the nozzle, each stabilizer generates a controlled recirculation pattern around its respective nozzle segment. A localized, highly turbulent region is thereby produced downstream of each segment. The result is a more stable flame and flame chemistry that enhances the NO_x control properties of this combustion process.

Development of the Opti-Flow™ fuel injector included two-phase half-scale flow modeling to verify the concepts and to optimize the geometry of the components. *Figure 5* is a photograph of the flow model in which alumina was used to simulate pulverized coal. The model was scaled for a burner fed from a vertical mill with a full load air/coal ratio of 1.8:1. However, testing was performed at a higher solids loading, averaging 1.4:1 air/fuel ratio. The combination of using a higher solids loading and a material with a higher specific gravity than coal resulted in an extreme test of the fuel injector's ability to remain clean—no solids layout or dropout.

Also of interest in the development of the fuel injector were two operational parameters, pressure drop and fuel distribution imbalance.

Minimizing pressure drop across the fuel injector, as measured from the inlet (coal pipe) to the nozzle's outlet, will reduce the system resistance against which the primary air fans operate. Also, pressure reduction at the burner can be used productively to balance coal pipes (orificing) and to improve coal fineness at the mill without increasing system resistance.

Minimizing fuel distribution imbalance around the circumference of the nozzle is necessary to control of NO_x and unburned carbon. Severe coal imbalance can simultaneously result in both higher unburned carbon and higher NO_x than a given burner design would generate if the fuel distribution were uniform.

Both pressure drop and fuel distribution were measured during development testing and were compared to similar measurements made on a standard commercial scroll burner supplied by a customer.

Table II compares the pressure drop, fuel distribution, and presence of layout between the standard scroll burner and the Opti-Flow™ design.

Table II

COMPARATIVE BURNER DATA

Burner Type	DP, "H2O*	Tip Dist., RMS (%)*	Layout
Std Scroll Burner	2.5	3.17	Heavy
Opti-Flow™	1.0	1.0	None

** Presented on a relative scale*

All fuel injectors must address the same problem in fuel feed: the coal pipe runs parallel to the windbox front plate while the fuel injector is perpendicular to it. Consequently, the primary air/coal mixture must make a 90° turn in order to enter the fuel injector. This results in a segregation, or "roping" of the coal as it leaves the turn even if the fuel particles were uniformly distributed across the coal pipe feeding the fuel injector.

Figure 6 illustrates this effect for both a 90° elbow and a scroll.

- In the case of the elbow, the fuel particles rope along the top of the elbow and remain segregated as they leave the nozzle. Mechanical mixing means must be used to correct for this problem.
- In the case of the scroll, the fuel particles collect along the scroll's periphery (as in a cyclone separator) and leave the scroll as a concentrated rope that maintains the rotation imparted to it by the scroll as it spirals down the fuel injector. As with the elbow, mechanical means must be used to break-up the rope if the imbalance is to be minimized.

The Opti-Flow™ fuel injector contains a method, located in the region of the transition, to redistribute the fuel particles so as to minimize the imbalance at the tip. *Figure 7* compares the fuel distribution leaving the fuel injector of the standard scroll design with that of the Opti-Flow™ design. The data are presented as relative air/fuel ratio at the tip. It can be seen that the fuel segregation generated by the standard scroll design results in relative air fuel ratios varying from 60% to 160%.

In contrast, the Opti-Flow™ design improves the variation to a range of 80% to 110%—a relative improvement of 3.17:1, RMS.

The significance from a combustion standpoint is that when fuel distribution is uniform, as shown by the 100% relative air/fuel ratio line, both NO_x and unburned carbon will be minimized for the given burner. The significant improvement in this variation, attained by the Opti-Flow™ fuel injector, is the approach to the optimum distribution. Lower NO_x with less unburned carbon impact than other burner designs should then be achieved.

Although the above data are presented for the scroll-based burner, the effect is the same for an appropriately designed elbow-based fuel injector.

Based upon the totality of these developmental results, and the guarantees ABT was able to provide, Deseret contracted for the conversion of all 20 burners on Bonanza Unit #1.

BONANZA #1 RETROFIT

The retrofit retained the maximum amount of existing hardware in order to minimize costs. The following lists the modifications made and the reason for each:

1. **Register Modifications:**
   - Replaced the original manually controlled, dual-track sleeve damper with a new single-track, electrically driven design.
   - Converted the original electrically driven outer register to manual control.
   - Replaced the secondary air flow divider with a more aerodynamic, less turbulent design.

These register modifications were made in order to de-couple the secondary air swirl, which is set for optimum combustion, from secondary air balance. They also eliminate unwanted turbulence and mixing between the secondary air and primary air/coal streams.

2. **Fuel Injector Modifications:**
   - Retained the existing scroll.
   - Replaced the outer burner barrel with the Opti-Flow™ assembly, as described above.
   - Provided an adjustable inner burner barrel of a new design in order to restore the ability to adjust the velocity of the primary air/coal mixture at the nozzle exit.

Installation was performed during a scheduled outage in the last two weeks of May 1997. Actual burner installation time was 11 days.

BASELINE AND RETROFIT TEST RESULTS

Approximately two weeks before the outage, Bonanza Plant personnel performed a comprehensive baseline test program with support from ABT. Data were obtained for the following:

- Boiler and emissions performance as functions of load and excess air.
- Mill fineness
- Fuel flow in coal pipes

The pulverizers were scheduled for maintenance after the outage. Since the boiler could maintain full load with any one mill out of service, the mills would be removed from service sequentially. Consequently, final burner optimization was scheduled to be performed after mill maintenance was completed.

Samples of the western bituminous coal burned at the plant were taken during the baseline tests. *Table III* lists a typical analysis.

Table III

TYPICAL COAL ANALYSIS	
ULTIMATE, DRY PROXIMATE, AS REC'D	
H: 4.80%	VM: 33.50%
C: 71.29%	FC: 45.54%
N: 1.48%	Ash: 8.84%
S: 0.55%	H_2O: 12.12%
O: 11.86%	
Ash: 10.02%	
HHV: 10,300 Btu/lb.	

Baseline mill testing included iso-kinetic sampling of each coal pipe to obtain both fuel flow and coal fineness on a per pipe basis. A modified ASME method, as developed by ABT, was used. *Table IV* lists the average mill fineness data obtained.

Table IV

PRE-RETROFIT COAL FINENESS		
(Prior to scheduled maintenance)		
Mill #	**<200Mesh**	**<50Mesh**
1.	70.42	99.22
2.	62.26	97.93
3.	66.26	98.21
4.	57.18	97.51
5.	59.27	98.10

The results of the fuel flow measurements are shown in *Tables V* and *VI*. *Table V* is presented to show the accuracy of the iso-kinetic coal pipe sampling when mass balanced to calibrated weigh belt feeders.

Table V

FUEL FLOW MASS BALANCE			
Mill #	**Feeder Flow**	**Meas. Flow**	**Deviation**
1	100,000	115,490	+15.49%
2	100,000	95,675	- 4.33%
3	100,000	96,139	- 3.86%
4	100,000	87,724	- 12.28%
5	100,000	100,743	+ 0.74%
Avg.	100,000	99,154	- 0.85%

The individual coal pipe flow measurements can be used to obtain the individual burner stoichiometry (S). Burners with high S will generate high NO_x and low unburned carbon, and conversely, those with low S will generate low NO_x and high UBC.

Table VI was developed from individual coal pipe measurements assuming equal secondary airflow to all burners. The latter assumption was based upon the earlier in-situ secondary airflow measurements performed by an outside contractor.

Table VI

PRE-RETROFIT STOICHIOMETRIES(%)				
(Based on 20% excess air)				
	BURNER #			
MILL#	1	2	3	4
1	**117.6**	**111.1**	**85.7**	**166.7**
2	120.0	115.4	**96.8**	**166.7**
3	127.7	117.6	125.0	111.0
4	**157.9**	**171.4**	120.0	**103.4**
5	**105.3**	127.7	122.4	**107.1**

Values in bold indicate those outside the range of 110 to 130 %.

A preliminary combustion optimization program had been scheduled to begin immediately after start-up with final optimization after mill maintenance was completed. However, NO_x was substantially below the guarantee level, and the only optimization testing that was performed was to compensate for the pipe-to-pipe coal imbalance and existing coal fineness. These conditions caused localized high CO/UBC values.

The only burner adjustments made were as follows:

- Registers were adjusted to obtain good stability at low loads commensurate with good flame shapes at high loads.
- Sleeve dampers were adjusted to attain good CO/O_2 distribution across the boiler's width along with low unburned carbon.

Testing was performed at low load (150 MWG) with three mills in service and at high load with either all mills in service or any one mill out of service. Figure 9 summarizes the NO_x vs. load results for the baseline and post-retrofit testing. At full load, NO_x is reduced approximately 30% from the as-found OEM low NO_x burner performance. Note that neither the OEM burners nor the Opti-Flow™ low NO_x burners were optimized for minimum NO_x.

Table VII summarizes the baseline and post-retrofit results and compares them to ABTÍs guarantees.

Boiler performance data show that superheat, reheat, and economizer exit gas temperatures are all in the same ranges as before the retrofit. There is no indication that the Opti-Flow™ low NO_x modifications have degraded boiler performance or efficiency.

ABT had predicted that burner throat eyebrows would be significantly reduced. This has occurred: eyebrows have been reduced to the point where they are no longer operational or maintenance problems.

CONCLUSIONS

The Opti-Flow™ low NO_x fuel injector and register modifications have reduced NO_x emissions by about 30% from the as-found levels obtained with an OEM's commercial low NO_x burner. There were no adverse impacts to boiler performance or efficiency or combustion efficiency. The boiler can now meet regulatory limits under all operating conditions, restoring unit flexibility and allowing maximum MW-hours to be generated. Unit reliability has been significantly improved by eliminating coking and burner eyebrows.

The success of this project confirms that it is not necessary to completely replace burners to attain substantial reductions in NO_x emissions. Similar modifications can be made to any wall-fired pulverized coal boiler. However, due to differences in boiler heat liberation and coal types, the absolute levels of NO_x and unburned carbon would differ from the results reported here.

ACKNOWLEDGMENTS

The authors wish to acknowledge, with great appreciation, all Bonanza personnel—management, engineering, operations, and maintenance —whose dedication, support, and trust permitted this project to proceed so successfully.

Table VII

TYPICAL PRE-AND POST-RETROFIT DATA				
	BASELINE	OPTI-FLOW™		GUARANTEES
Load (%MCR)	100	100	100 @ 5% OP	100 @ 5% OP
NOX (lb/106Btu)	0.55-0.60	<0.40	<0.45	<0.45
CO (PPM)	<50	<50	<50	<100
UBC (%)	2-4	2-4	2-4	No Meas. Incr.
Coking & Fires	YES	NO	NO	NONE

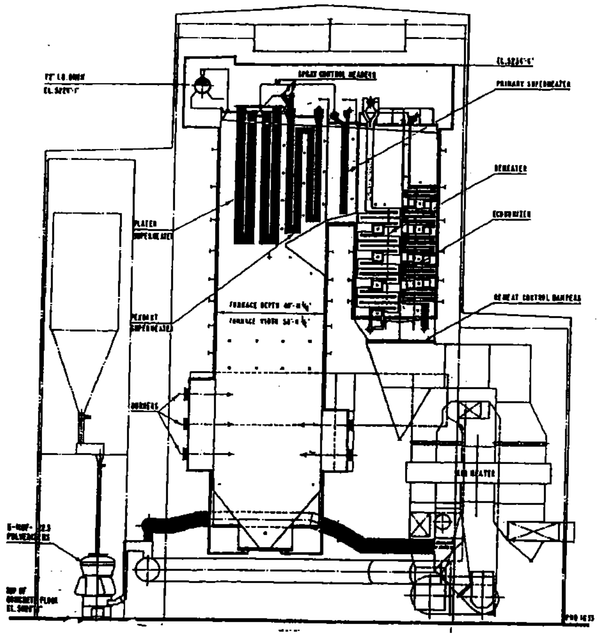


Figure 1 Bonanza Unit #1

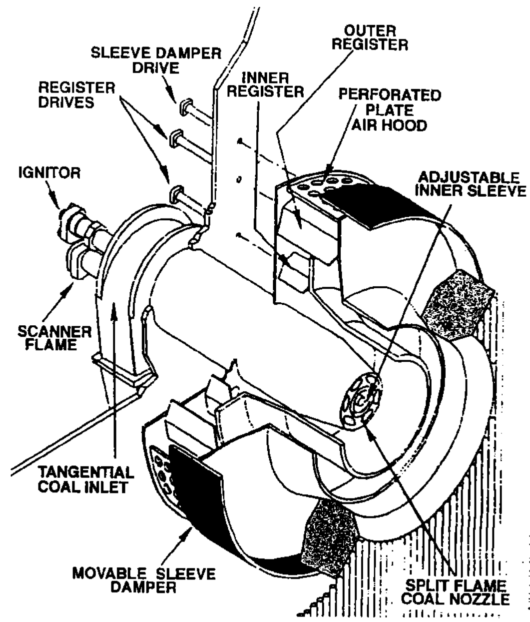
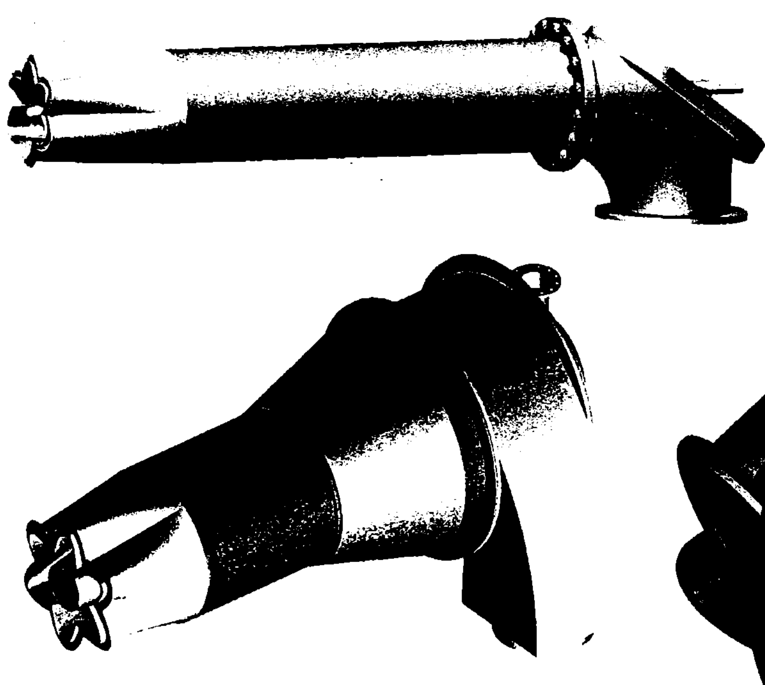


Figure 2 OEM Low NO_x Burner



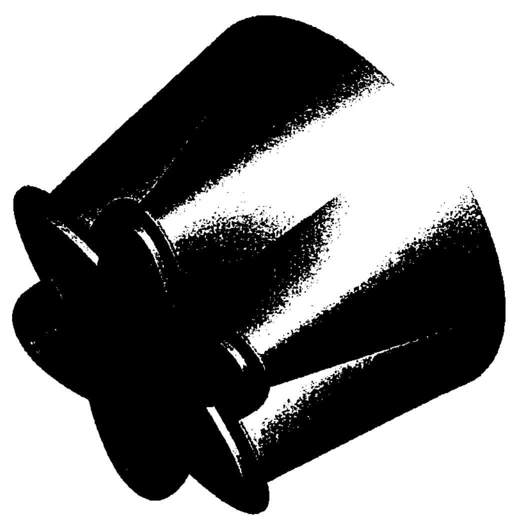


Figure 3 Opti-Flow™ Fuel Injector

Figure 4 Opti-Flow™ Segmented Coal Nozzle

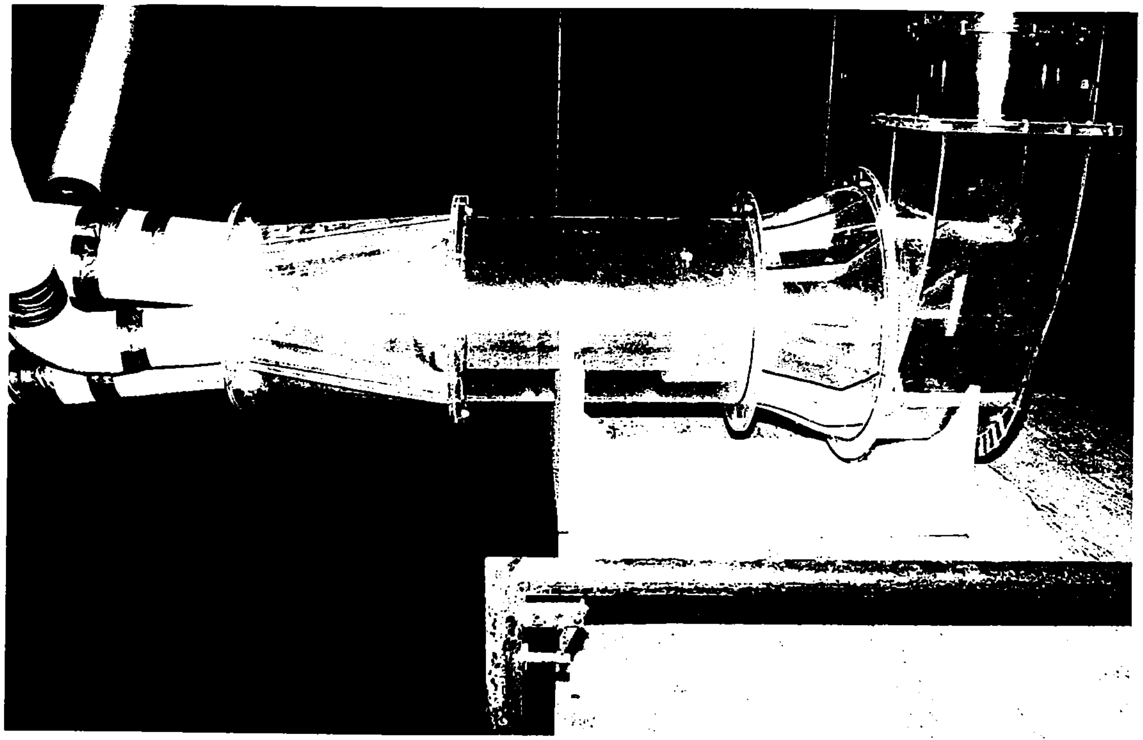


Figure 5 Opti-Flow™ Two Phase Model

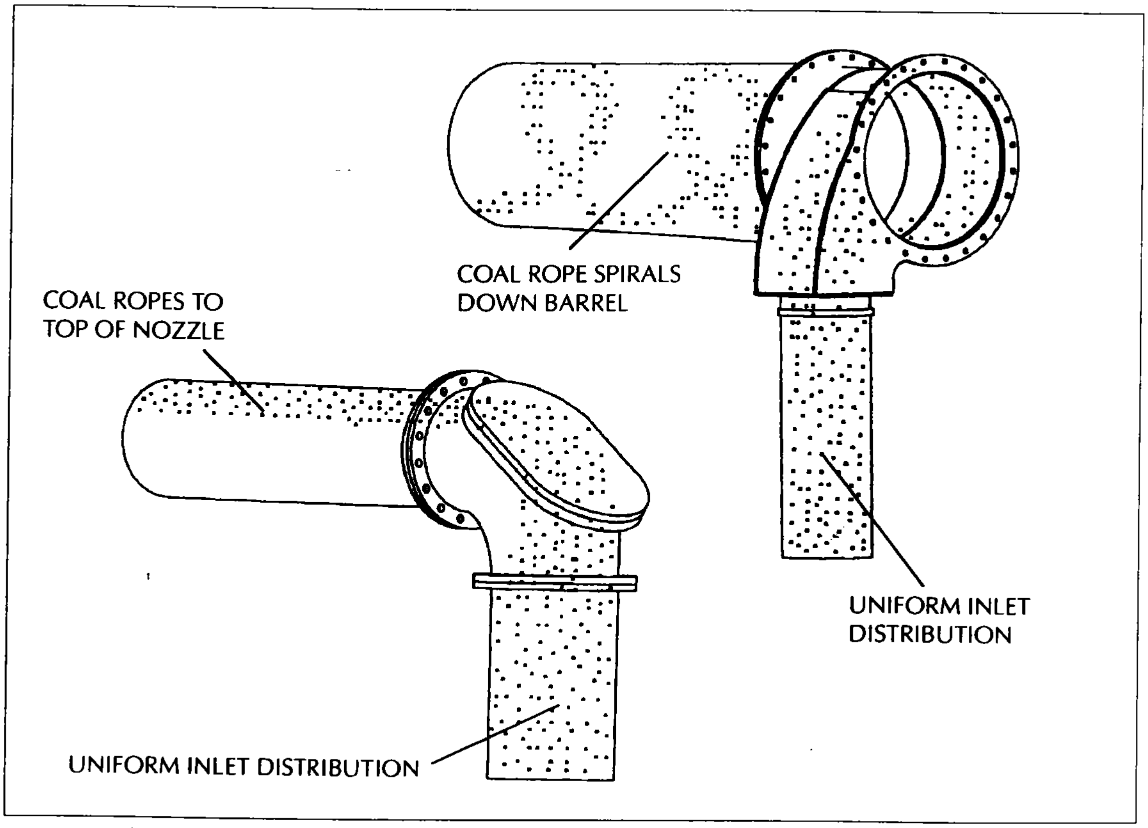


Figure 6 Coal Roping: Scroll & Elbow Fuel Injectors

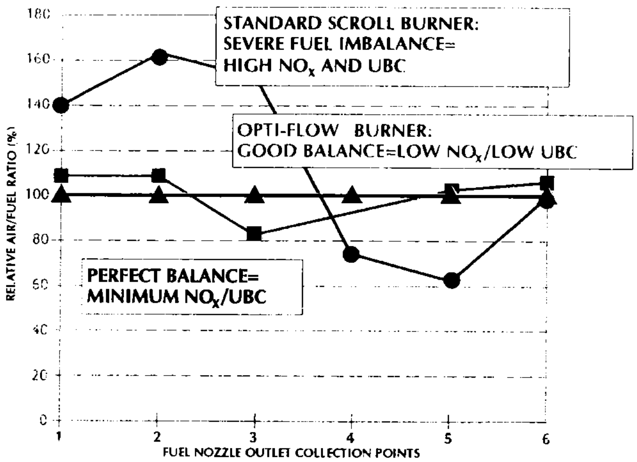


Figure 7 Fuel distribution at Nozzle Exit

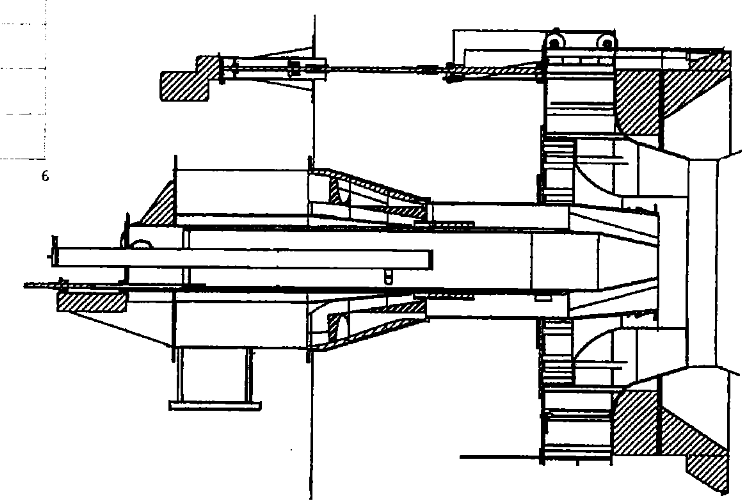


Figure 8 Opti-Flow ™ Modifications to OEM Low NO_x Burner

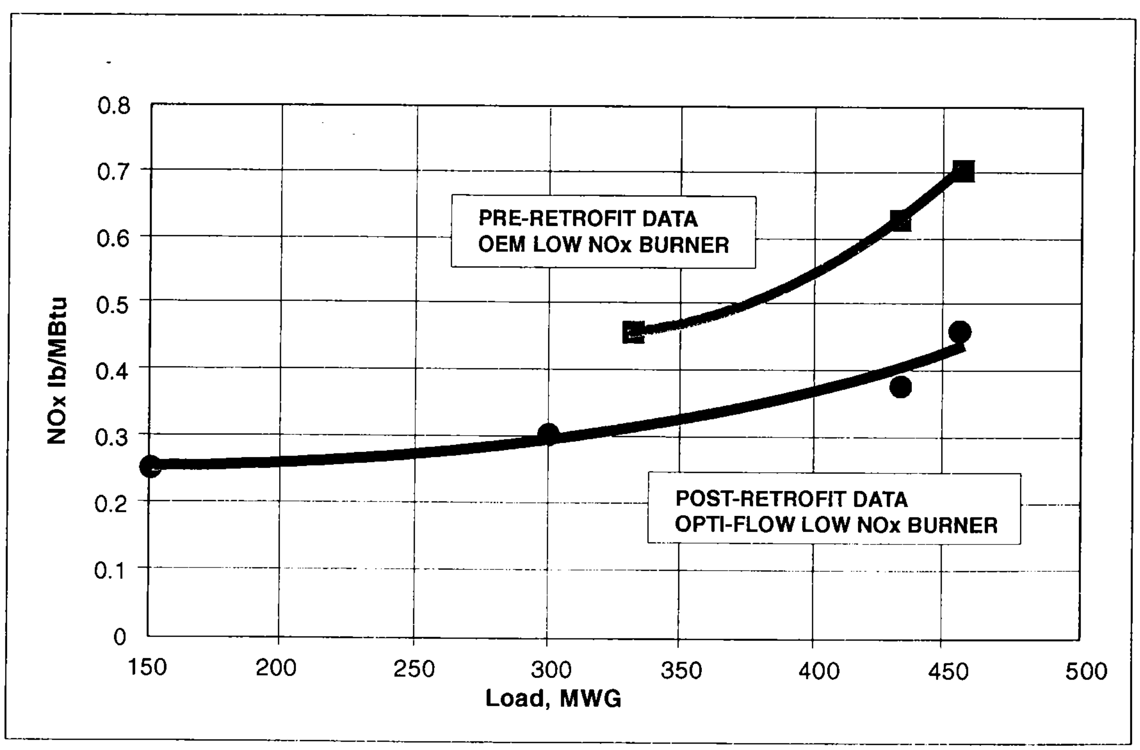


Figure 9 Baseline vs. Opti-Flow ™ Low NO_x Burner